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Drone usage for pavement damage identification

Abstract: The timely use of appropriate renovation measures can effectively extend the life of road surfaces. For this purpose, it is necessary to carry out a detailed identification of damage, and then on its basis to assess the condition of road surfaces. Due to the development of advanced measurement techniques and computer applications, damage to pavements can be monitored faster and more accurately. This article presents a method of identifying damage to the pavement of a large area of the square with the use of a drone. The applicated method allowed to visualize and differentiate various surface defects faster and more preciously. The method also enabled determine causes and genesis of damage more greatly.

Keywords: Drone; Pavement damage; DJI SPARK, Damage Identification

Introduction

Without proper repair procedures, road surface degradation will occur faster, which will be associated with significant economic losses in the later period of operation. In order to maintain the roads, an appropriate inspection of the condition of the surface should be carried out. Unequivocal identification of pavement damages, their formation manner, and prospects for further development require advanced, often complex research, followed by mechanistic analyses. Visual techniques are most often used in the surface identification process. They have been supplemented for a long time by image recording techniques [2], [5], [8], photogrammetric methods [17], [6].

Although the first flying objects were used in the 19th century (small balloons for war purposes) and then radio-controlled unmanned aerial vehicles, the actual development of drones (unmanned aerial vehicles, or UAVs) began at the end of the 20th century. Today's drone market can be divided into drones for military and civilian applications (private, industrial, and scientific research). In the field of road construction, drones are useful in places inaccessible to vehicular traffic or for the identification of large areas. Photo and video recording is used using cameras/cameras attached to drones [7], [9], [12], [1], [13].

Particularly noteworthy is the previous work [18], in which drones were used (for the collection of data in the form of images) to assess the condition of unpaved roads. The authors [11] used drones and appropriate software in earthworks projects, comparing the results with the conventional geodetic method. Economic considerations requiring an effective method to monitor large construction areas indicate the need for drones and the MATLAB GUI interface to detect and evaluate surface cracks of various objects [10].

Systematic documentation allows for future analysis of changes in the development of pavement damage and the use of an appropriate model.

Currently, surface monitoring is carried out in Poland, and many systems are used in the local and global scope of the road network. Using various mobile equipment, the bearing capacity of the pavement, surface features, and damage conditions are identified. The use of video technology and high-resolution cameras allows for continuous recording of various types of damage and then using multiple algorithms (e.g. artificial neural networks) to classify them and determine their parameters.

In Poland, manual or semi-automatic registration systems have been used for many years. In 1989, the Pavement Condition Assessment System (SOSN) was introduced in Poland [15]. It was based on an inventory of damages and measurements of the operational characteristics of asphalt pavements. The visual identification system was developed and updated over the years [14], [16]. The SOWA system was used for the inventory and visual assessment, based on the manual concept of damage coding via a unique recorder while driving. Due to direct human handling, it contained some aspects of subjective evaluation. Using SOSN studies, research development, and foreign experience, detailed guidelines for pavement condition diagnostics (DSN) were developed and collected.[4], [3]. Although the UAV technique is not yet included in this system, the currently used LCMS (Pavemetrics®)—Laser Crack Measurement System—allows for continuous, precise, and repeatable identification of damage on the surface (Fig. 1). This automatic assessment of the condition of the road surface is based on taking a high-resolution 3D image of the road surface and photos using cameras that record a general view of the roadway from the front and rear of the vehicle. Specialized "high-speed" cameras record the image of the road surface along with the image of the laser line generated by laser projectors. This technique produces a 3D image that is used for automated analyzes aimed at detecting surface damage (including width and depth, if applicable).

The use of drones in road construction is not yet widely used and required in road network management systems in Poland. Despite this, many scientific units or road companies use drones for photo and video recording, in particular for monitoring, inspection of works, assessment of damage, and assessment of traffic conditions. More advanced registrations are also implemented, such as thermal analyzes or 3D numerical registrations, which are then used to develop digital surface models (DSM) and digital terrain models (DTM)).

Site vision allows you to identify areas of land and roads in one shot. This turns out to be effective in maintaining the safety of people performing the inventory and access to remote places that may not be included in the classical approach. Drone technology is extremely effective when it comes to recording such surface damage that is difficult to locate and reference over large areas, e.g. on runways, squares, car parks, extensive internal road networks.

Content captured by drones at a later stage should be properly processed in terms of graphics and calibrated in order to develop visual photographic maps with the required detail.

However, it should be noted that in specific situations (e.g., searching for causes of unusual damage, analysis of smaller local areas), it is still necessary to identify and analyze damage in the "manual" system. This study presents the use of a drone as a tool to effectively supplement a typical inventory of damage to the surface of a large square.

Characteristics of the square

The aim of the research and inventory carried out by the authors was to analyze the causes of damage to the wearing course (made of prefabricated concrete elements) and elements of linear drainage on the surface of the square in front of the public utility building. The analyzes were carried out for the purpose of developing a repair program for the surface of the square. The condition of the cracks and evenness of the surface, damage to expansion joints and joints, as well as linear drainage elements, were assessed. As part of a later study, field observations were verified in a computational model. Numerical analyzes were carried out, indicating the causes of damage. Repair technologies protecting the square against further degradation were indicated.

The surface in question occupies a square with an area of over 10,000 m^2 on the slab of the underground garage. It is a rigid and tight structure, dilated with the following arrangement of layers:

- wearing course made of concrete/granite slabs and cubes, 8 cm thick,
- sand-cement bedding, 3-5 cm thick,
- waterproofing protection layer made of C12/15 concrete with a variable thickness of 5 - 31 cm,
- waterproofing,
- concrete layers of the garage slab.

The joints are filled with cement mortar to a depth of min. 4 cm, and the width of most joints is from 2 to 8 mm. The general view of the pavement is shown in Figure **1**.

1. A fragment of the analyzed square

Equipment used

The DJI SPARK drone, which is relatively unadvanced for current technologies, was used for the damage inventory (Figure **2**). It is a quadrocopter device that was released on the market in 2017. It has small dimensions of 143 x 143 x 55 mm and, what is very important, it has a take-off weight of only 300 g (150 g without the drive package). As a reminder, the then-Polish administrative regulations governing drone flights concerned machines weighing between 0.6 kg and 25 kg. Drones under 0.6 kg did not have restrictions on flights near crowds of people and in built-up areas. Currently, every person who wants to fly a drone weighing more than 250 g will have to undergo online training and pass an online test confirming the acquisition of the required knowledge.

The low weight of the drone is advantageous, as it is more resistant to possible mechanical damage in the event of a fall and potential threats to people. The SPARK drone has foldable propellers for transport and a convenient case for convenient transport. Several automated programs-functions are available for recording shots, making it easier to take professional shots. After switching to Sport mode, the model can move at a speed of up to 50 km/h. This mode can also be used to quickly move to the place of filming, and then return to the target registration area after turning it off. The factory's maximum flight time is 16 minutes and the maximum climb/descent speed is 3m/s. The device uses an extended Combo set that provides a greater control range, faster loading of drive packages, greater control precision (RC/Video transmitter), and flight safety (propeller guards). LiPol 1480 mAh/3S power pack was used. During the inventory, a single top-up was required (package charging time approx. 1 hour.

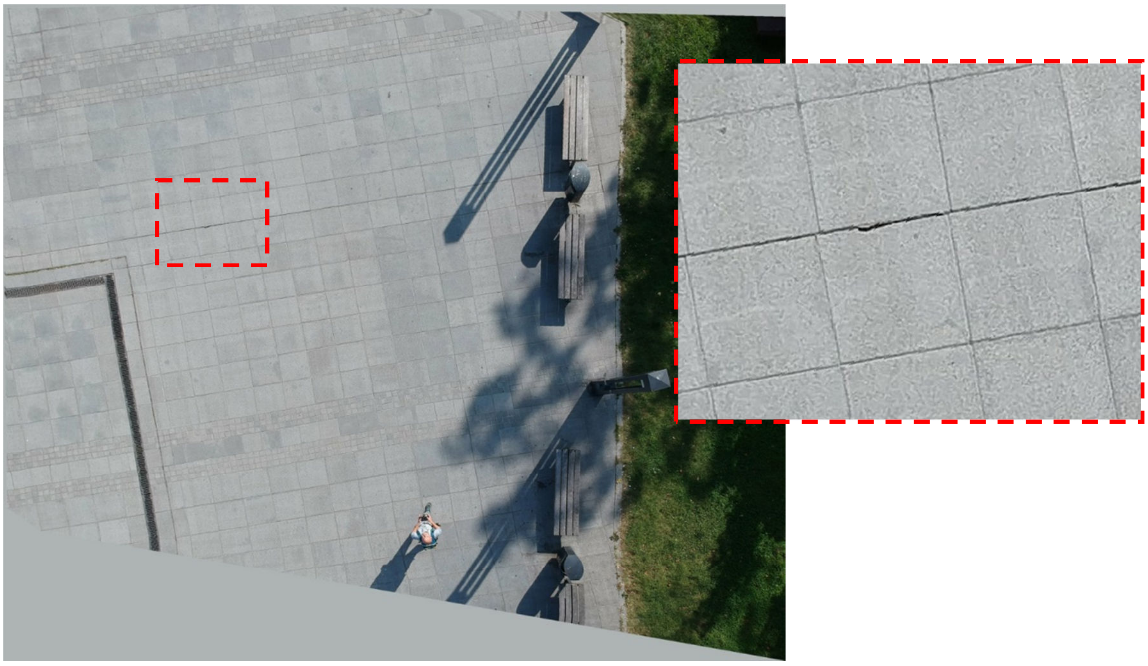
A camera was used to record the image: 1/2.3″ matrix, 12 Mpixels, FHD format: 1920 x 1080 and 30 fps, 25 mm camera lens, lens brightness f = 2.6. The control was carried out with an RC/Video transmitter allowing a range of up to 500 m. Signal transmission between the model and the transmitter is digital in the 2.4 GHz band for RC and 5.8 GHz for video. Control in the WIFi system allows for a range of up to 100 m in distance and 50 m in height.

The drone is additionally equipped with: a GPS/Glonas receiver, a barometric altitude sensor, a magnetic compass, sensors against a collision with an obstacle in front of the model, sensors for precise landing and maintaining the position in closed rooms, a sensor for recognizing the face and gestures of the operator or tracking a designated object. For flight stability, the permissible wind speed is 28 km/h.

2. Drone with equipment

Damage identification

In order to identify the damage to the square in detail, a series of photos was taken using the DJI SPARK drone (Figure **3**).

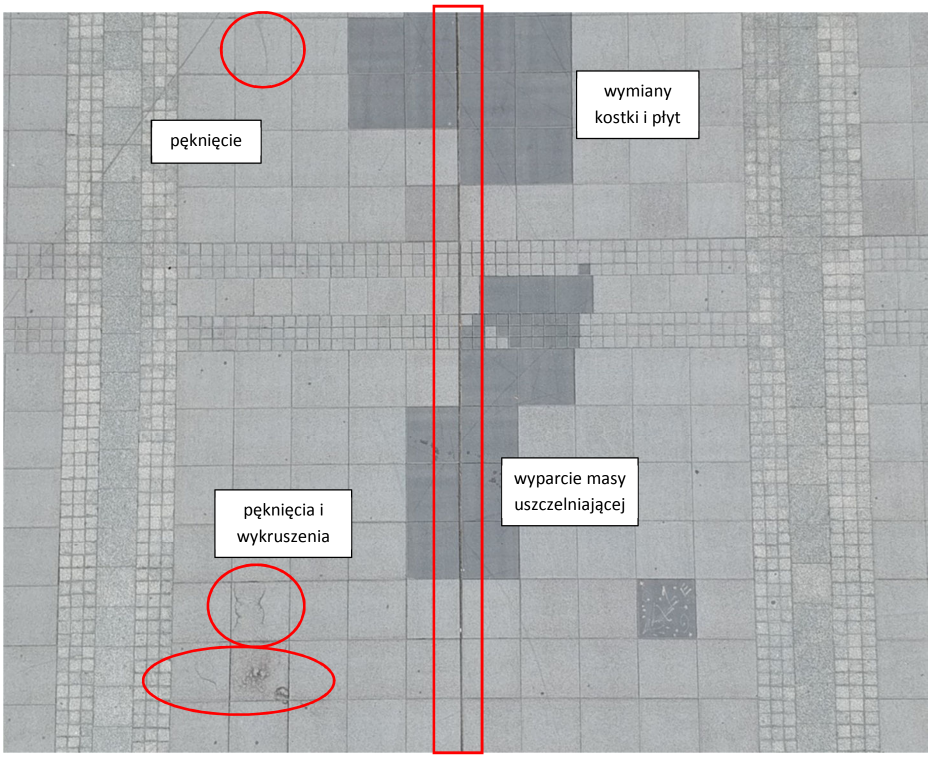


3. Sample photos taken by the drone

The registration of the area was recorded in the form of photos with a resolution of 12 Mpixels, taking into account the "overlap" of photos, which was useful in the next stage of calibration and combining photos. About 400 photos were recorded for the analyzed square. During the inventory, there were good weather conditions, little wind, and no precipitation. In some areas, there were shadows from trees and objects, which required additional graphic processing of images at a later stage (Figure **4**).

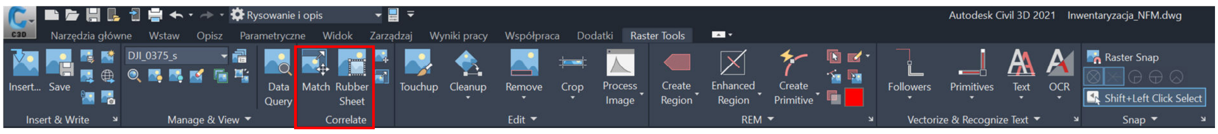
4. Sample photos of image correction due to area shading

Most of the images had similar tonal characteristics and allowed for the unambiguous identification of surface defects. An example of a square fragment with marked damage is shown in Figure **5**.



5. Photo of an identified damages of the registered square

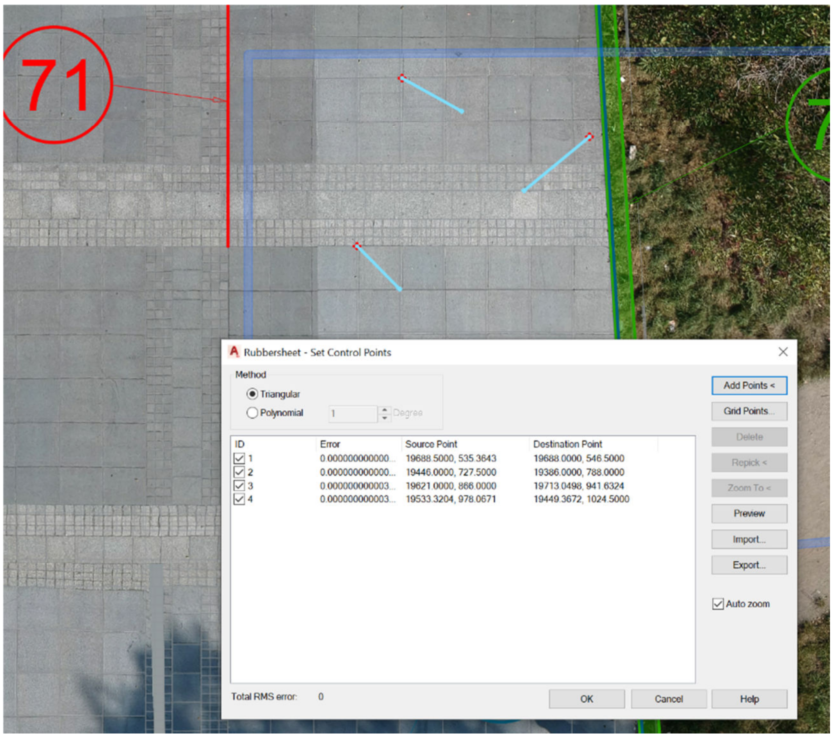
In order to create a comprehensive, detailed damage map, it was also necessary to calibrate each image. It was caused by some distortion due to the shorter focal length and aberration at the edges of the image. The shorter focal length of the lens allowed for a wider angle of the lens and taking fewer photos. There are many photo processing programs - Adobe Photoshop, Gimp, and Google Picassa, but none of them allows for direct and efficient modification of images for engineering applications. In the Autodesk environment, there is an extension that the user can optionally install to the basic Autocad - Raster Design. It also works in programs such as Autocad Map3D and Civil 3D. It allows you to edit photos in terms of creating map backgrounds and converting them to vector objects. This tool was used to calibrate and combine the recorded images. In the software interface shown in Figure **6**, there are many useful options for processing the photo inserted into the Cad environment.



6. Raster Design overlay interface in Autocad Civil 3D environment

One of the most important options is Match, which allows you to indicate the starting and target points of the image, so as to simultaneously perform the displacement and scaling of the photograph. The second Rubber Sheet option allows you to "stretch" the characteristic points of the image on the design state contained in the documentation, thus creating a real view on a 1:1 scale. This has been used e.g. when connecting road edges, edges of small-sized elements, expansion joints, curbs.

When calibrating in the Raster Design tool, the user has two methods of calibrating the image - "triangular" and "polynomial". The first method was used, which is very accurate. An example view using the Rubber option is shown in Figure **7**.



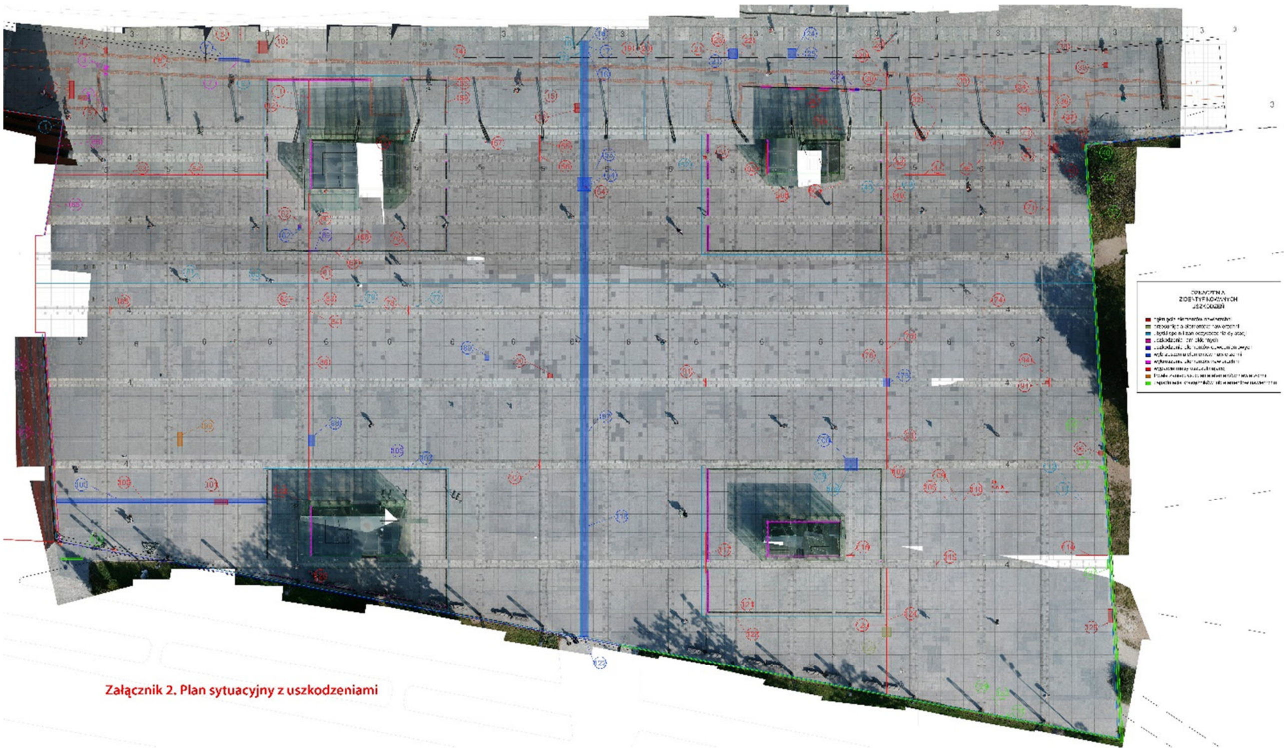
7. Image distortion - the Rubbersheet option

It should be noted that to create a map of the real state without deformation, the original images must be calibrated and properly cropped, which is allowed by the Raster Design extension. When recording images with the drone, each area partially overlapped. After calibration, overlapping image fragments were cropped. In this way, a coherent area without visible discontinuities was obtained (Figure **8**).

8. An example of the output of a damaged object's calibrated map

The discussed steps and the capabilities of the Autocad - Raster Design software made it possible to develop a site plan of the entire yard with damage and, at a later stage, to analyze the global nature of the mechanics of the entire yard.

The result of the calibrated base applied to the design documentation with damage markings is shown in Figure **9**.



9. Site plan of the entire square with damages

Damage analysis

The inventory of damage from the drone was supplemented and verified during a classic site visit. The inventory carried out indicated the presence of:

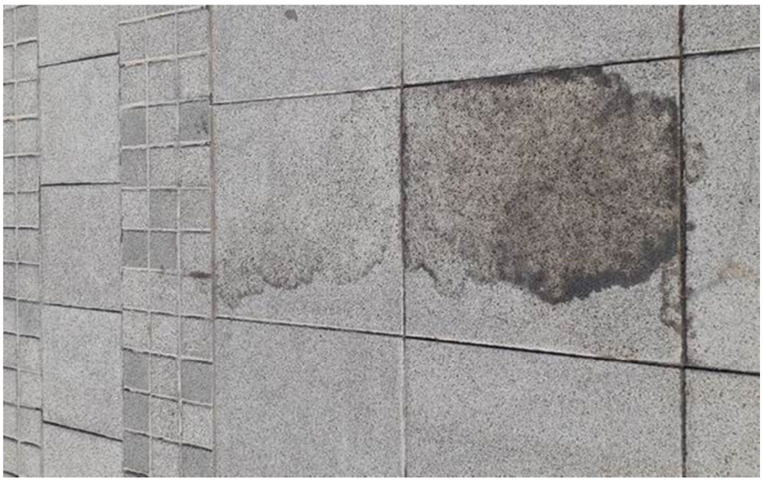
• cracks in pavement elements
• displacement of pavement elements
• defects in joints and contamination of expansion joints
• window frames damage
• damage to the elements of the linear drainage system
• bumps in pavement elements
• chipping of pavement elements
• displacement of the sealing compound
• permanent impurities of pavement elements
• collapses/shifts of curbs or pavement

Examples of damages made using the photographic technique with a classic camera are shown in Figures: **10 – 15**. This technique allowed for more accurate measurement of various damages and introducing them into a comprehensive site plan.

10. Examples of panel cracks (in the middle and on the edge)

11. An example of shifting pavement elements

12. Examples of sealing mass displacement



13. Examples of permanent contamination of pavement elements

14. Examples of curb collapses/shifts

15. An example of the bulge of pavement elements

It was found that the identified damages are primarily a consequence of thermal impacts (limited movement of small-sized elements), and partly the impact of vehicles. The global analysis of the area using drone images indicated three distinct mass bulges/extrusions

(1-3 cm), which were determined based on global damage identification (Figure **16**). It should be noted that the entire area of the square is currently "divided" into four slabs (approximately 40 m wide), limited on the one hand by the impact on the building (directly on the window frames), and on the other by the curb (which has been moved into the green area). The consequence of significant displacements of up to several centimeters is the pressing of the mass from the cracks or its crumbling. Damage to the joints may cause further degradation of the lower layers as a result of water penetration into the pavement.

As a result of the horizontal displacement of the slabs, the linear drainage elements were also damaged. For them, separate areas susceptible to the impact of large horizontal forces were distinguished. Damage to the channels and grate gratings was found, preventing their proper operation.

Some cracks in the pavement elements are wider than 3 mm and pose a risk of chipping from the pavement, which may pose a threat to pedestrian traffic. The identified shifts of the surface (slabs) are an unsightly visual element, as are stains and other color changes. More important are several-centimeter deformations of the curbs, which may affect the pollution of the square and water outflows.

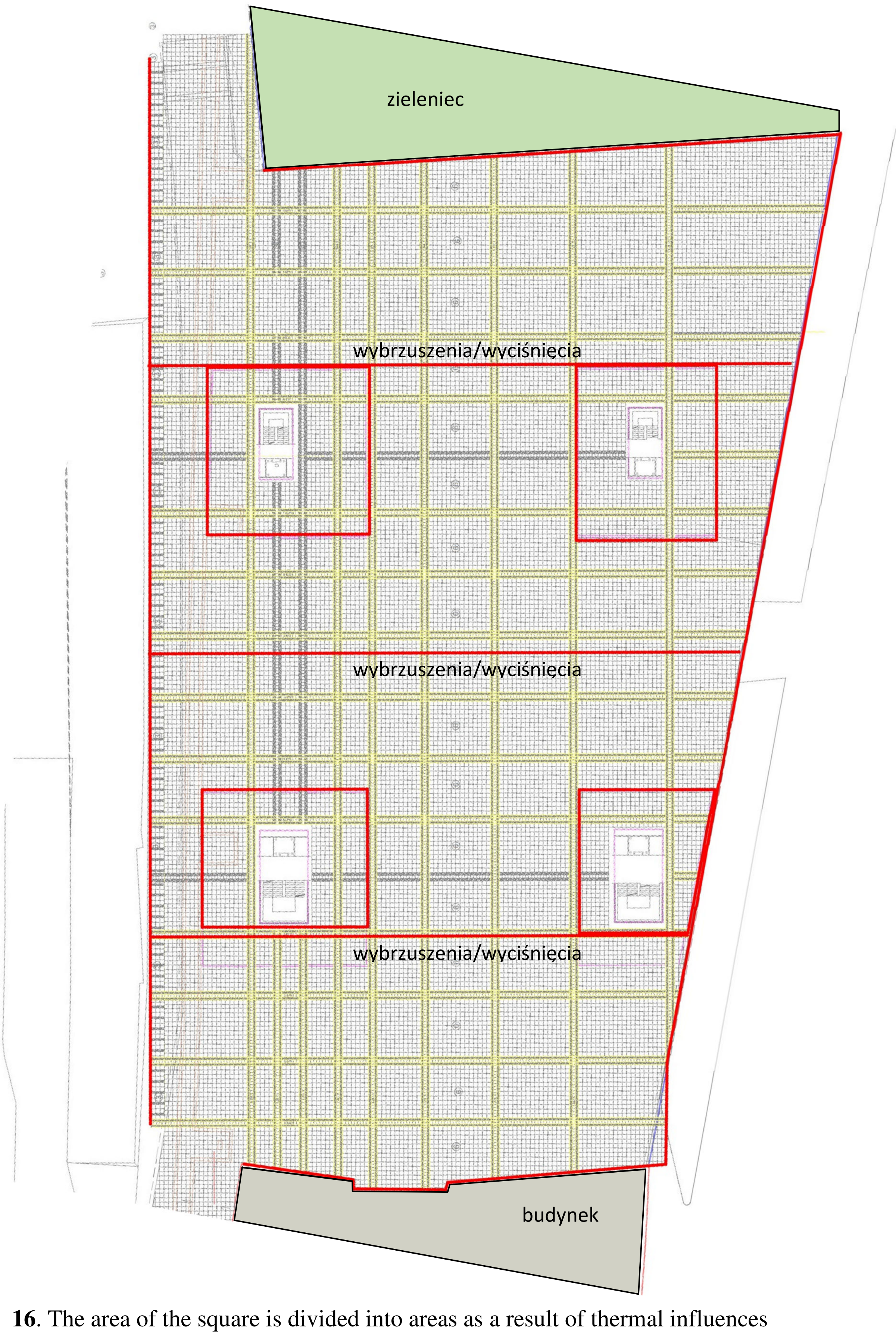
Summary

Based on the conducted considerations, the usefulness and high efficiency of the use of drones for monitoring damage on large areas of the pavement are stated. The use of these devices and appropriate software allows you to create a comprehensive situational plan of the existing state, which is applied to the design documentation and is a complete material for analyzing the condition and causes of damage. This image also allows for the development of cost analysis and the implementation of optimal repair treatments in selected areas of the area. However, it should be remembered that recording devices should have appropriate technical parameters to ensure adequate image accuracy. According to the current regulations, you must follow the safety rules and have the required training and permissions in the use of drones.

The method of using a drone to take pictures and capture video was undoubtedly helpful in assessing the causes of damage to the square. The pavement made of concrete slabs lacked appropriate technological solutions. The cause of the described thermal damage is the over-stiffening of the constructed structure and the ratio of the thickness of the expansion joints to their dimensions in the plan is not maintained. As a result of too large spacing of expansion joints, or practically the lack of them, the critical length of the slab was exceeded and the space for its movement was limited.

The global list of damages on the overall plan indicated the accumulation of cracks, and bulges of the pavement, separating the square area into four large areas indicating the mechanism of work. Damage to gap fillings, "bulges" of the surface, damage to drainage elements, damage to window frames, and other surface damage occurred as a result of significant thermal displacements, due to improperly dilated square. In some areas of the square, the low-temperature conditions in which the paving was paved may have contributed to this. This situation also caused a greater difference in temperature from the construction period to the operation period in the summer.

Great appreciation to Mr. Leszek Ziołkowski for providing technical equipment and recording images with the use of the DJI SPARK drone.



16. The area of the square is divided into areas as a result of thermal influences

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